CsI Crystal Processing Summary

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CsI Crystal Processing

- Acceptance testing.
  - inspection, metrology.
  - light yield vs position w/ ^{22}Na source (PMT dry mount, both ends).
- Surface processing (Ukrainian crystals only, Crismatec delivered with light taper).
- Crystal resizing (Ukrainian only).
- End treatment.
  - a) blacken with aperture for PIN photodiode or
  - b) white Tetratek.
- Light yield vs position w/ ^{22}Na source.
- Mount PIN photodiodes.
- Final optical wrap.
  - Tetratek (2 x 10 mil).
  - Aluminized mylar with adhesive.
- Muon testing (and ^{228}Th source).

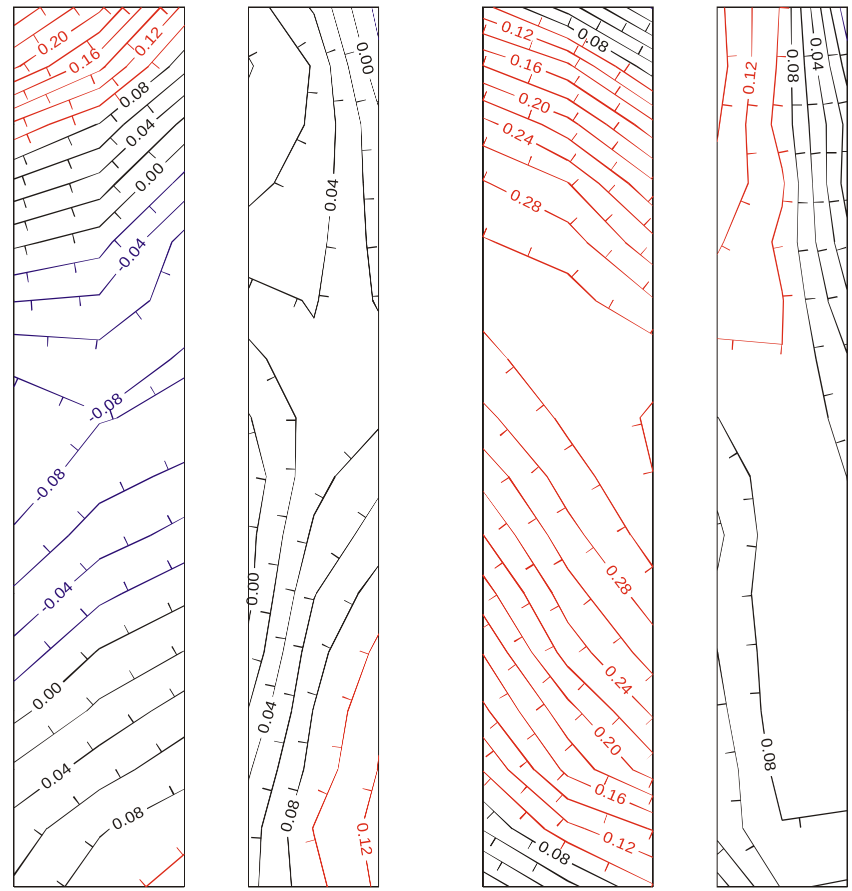
Beam Test Calorimeter Prototype CsI Status

- All 90 CsI crystals (310 x 30 x 23 mm) have been received and acceptance-tested at NRL.
  - 40 Crismatec, 50 Amcrys-H (Ukraine).
- 10 40-cm crystals have been received from Ukraine.
  - 6 have been cut to 37 cm and surface-treated. Sent to France.
- Ukrainian crystals were delivered with fine polish. We applied light taper.

- Visual inspection
  - Crismatec:
    - Clear as glass. Typically one or two small, dark inclusions. Rare internal crystal flaws, crystal boundaries.
    - Fine polish on ends and two surfaces. Occasional small surface flaws. Scratches, chips.
  - Ukrainian:
    - Milky. Typically one or two dozen small, dark inclusions. Occasional internal crystal flaws, crystal boundaries, small cracks.
    - Surface polish is not as fine as Crismatec. All have thin smudge line from adhesive in wrapper. Occasional surface flaws, scratches, pits, chips, cracks, crystal boundaries, goobers.

Crystal Metrology

- Metrology summary
  - Bars are typically too large in cross section by ~0.1 mm.
  - Large-scale (> few cm) surface variations of order 0.1 mm.
  - Crismatec crystals are superior to Ukrainian. Dimensions are closer to spec. Surface variations are smaller in height. e.g. one Ukrainian is warped by ~0.3 mm.



Worst crystal: Ukrainian U-02-21.

Units are mm.

Contours are 0.02 mm.

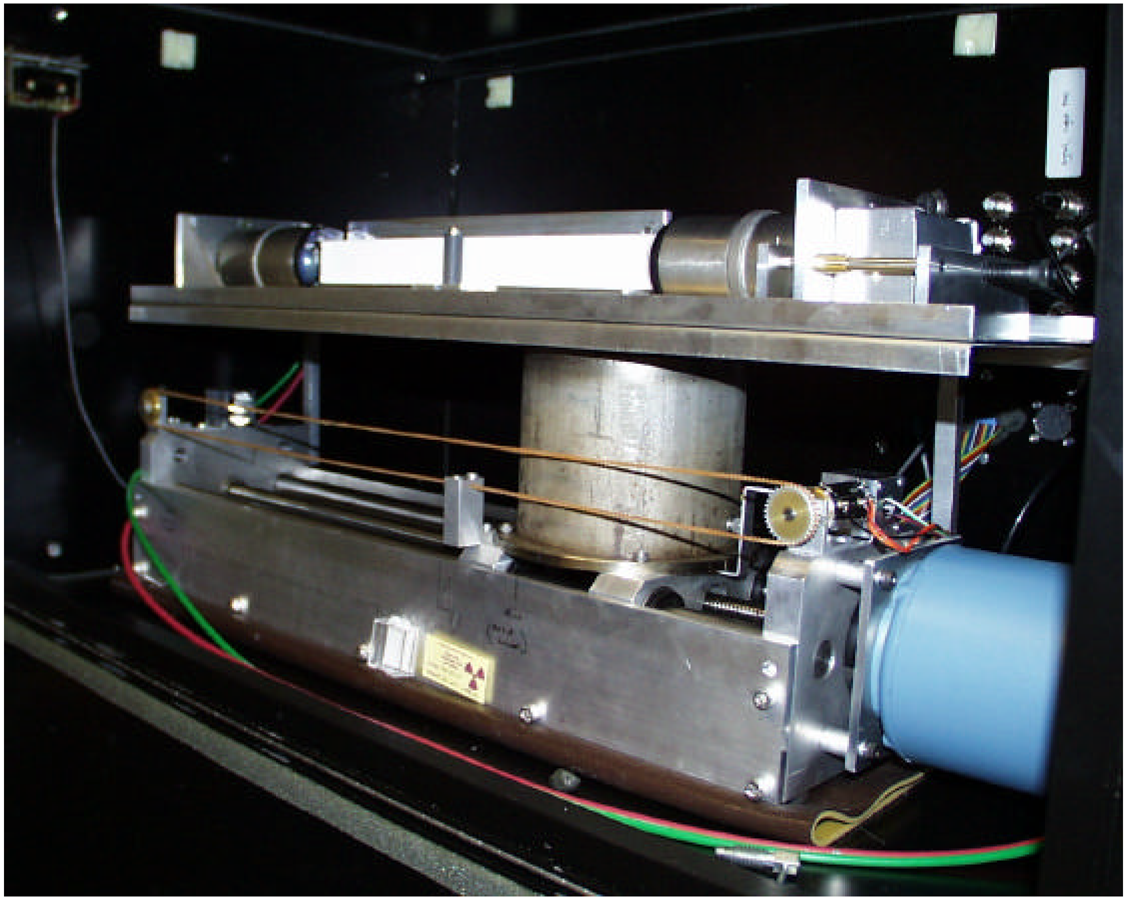
Red: More than ±0.1 mm from spec.

Black: 0.0 to +0.1 mm from spec.

Blue: -0.1 to 0.0 mm from spec.

Crystal Testing Station

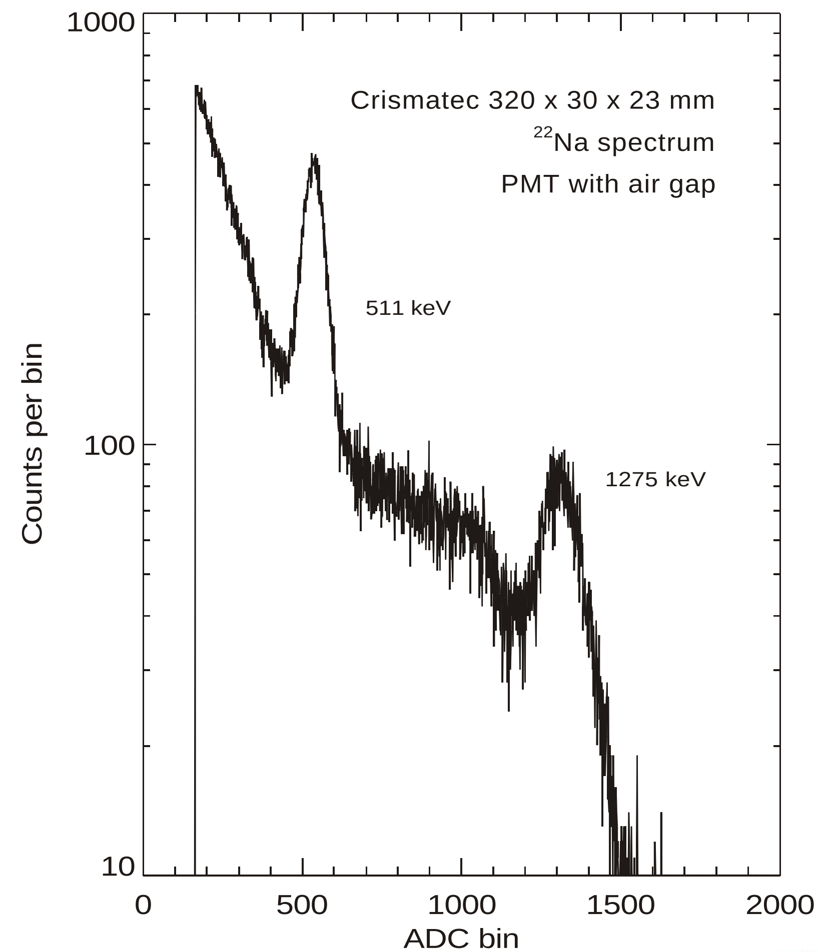
- Map crystal response as a function of position.
  - ^{22}Na source scanned along length of crystal.
  - Red-sensitive PMTs at both ends.
    - Hamamatsu R669.
- Fully automated scanner acquires map in 40 minutes.
- IDL analysis s/w fits 1275 keV peak and generates map hardcopy.



Crystal Test Procedure

- Crystals are numbered and inspected as delivered.
  - Factory wraps are Teflon-only or Tyvek and aluminum foil.
  - Additional wrap of aluminized mylar is added if necessary.
- Various end treatments may be applied as required for test.
- Crystal is mounted between two R669 2” PMTs.
  - Air gap between crystal and PMT.
- ^{22}Na or ^{137}Cs source is scanned along crystal with motor drive.

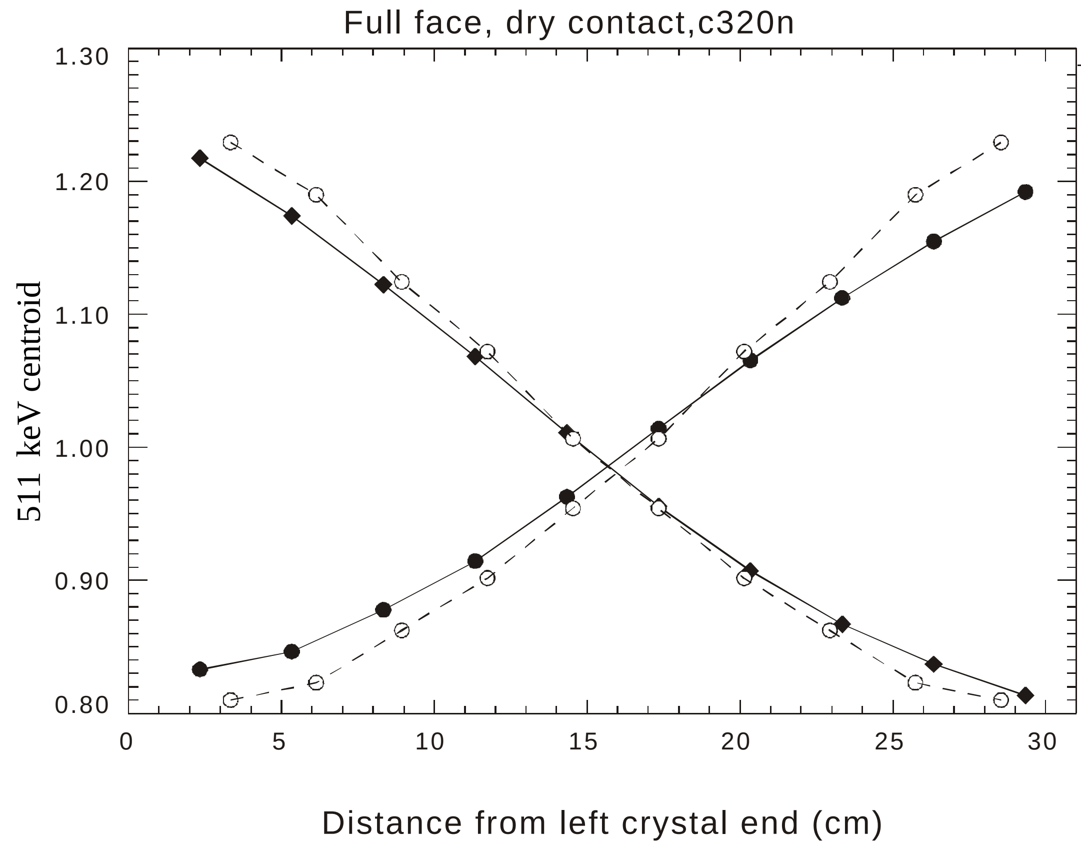
- Good spectroscopy is achieved.



CsI Light Tapering
Crismatec Material

- ^{22}Na source scanned along length of crystals.
- Crystals arrive from factory scanned from one end. We scan simultaneously from both ends.

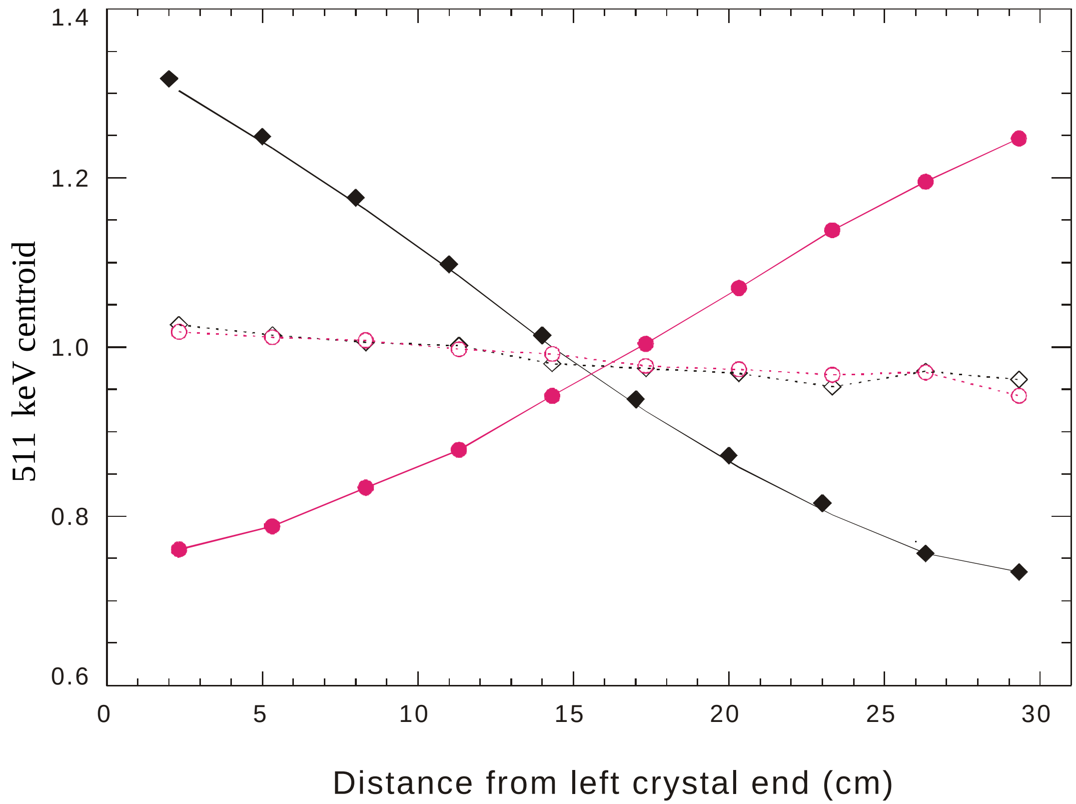
- Crismatec crystal with factory surface treatment and factory wrap.
  - Open symbols: factory testing.
  - Filled symbols: NRL testing.
  - Normalized to mean response.



Surface treatment of Amcrys

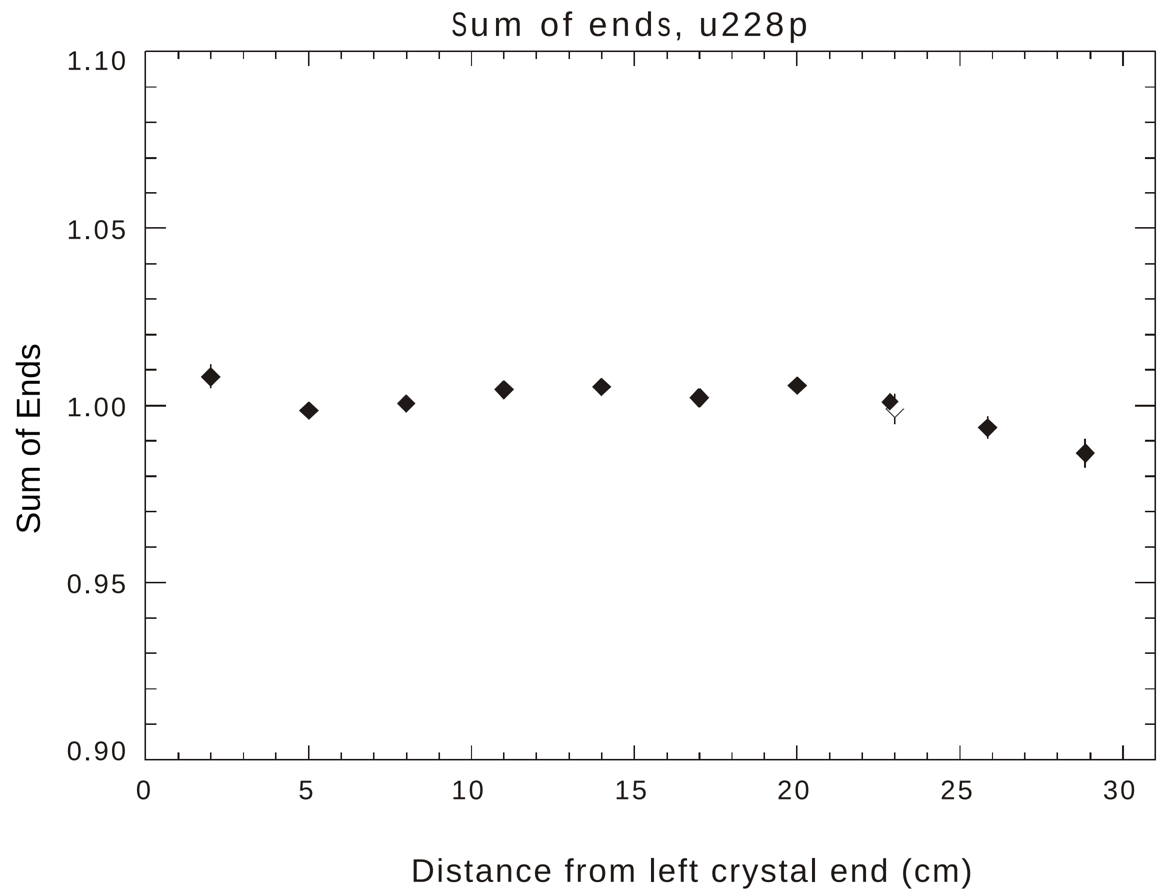
- Ukrainian bars arrive with “fine” polish.
  - Light collection ~ uniform, varies by dopant.
  - (red and black curves, open symbols).
- NRL surface treatment gives tapering equivalent to Crismatec.
  - (red and black curves, filled symbols).
  - Treatment leaves absolute light yield ~ unchanged.
  - Can tune treatment to give desired slope.
  - Bars with slope too steep can even be flattened!

Full face, dry contact, u207s



Light Tapering
Total Light vs Position

- Tapered bars still give good energy resolution: Sum of two ends is nearly constant.
- Crismatec from factory and Ukrainian after surface treatment achieve similar performance.

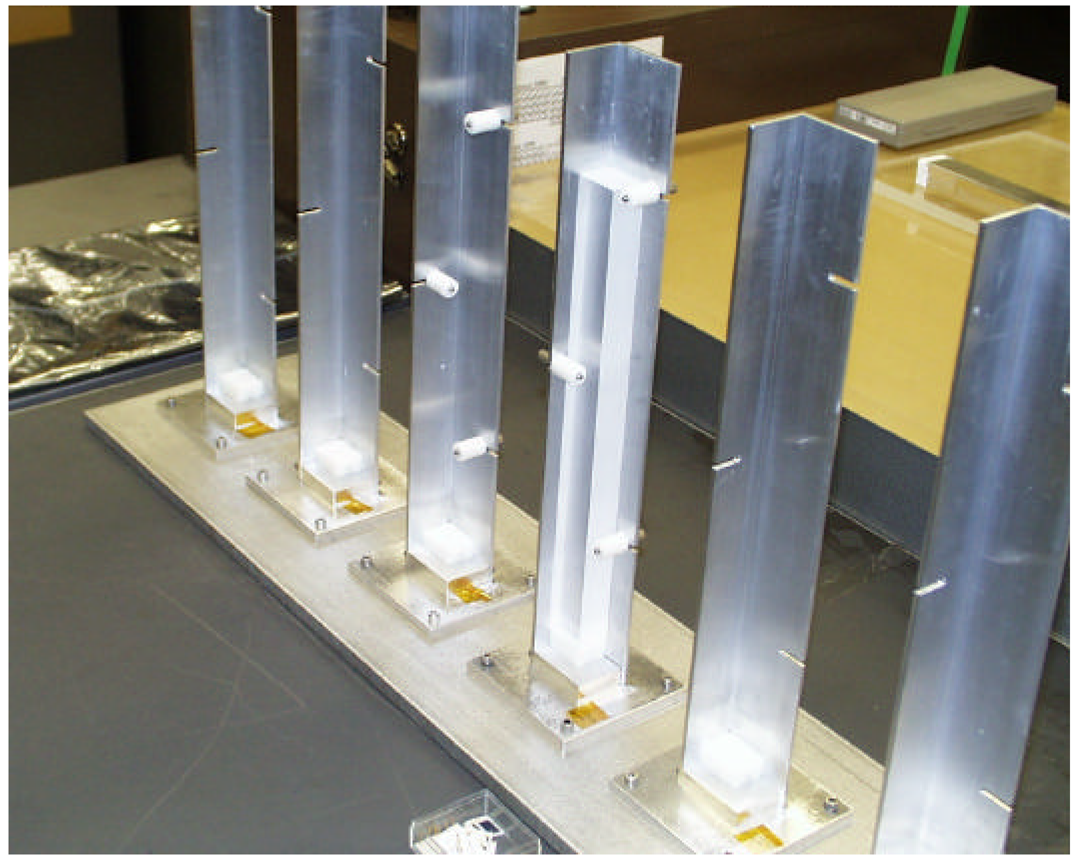


Ukrainian U-02-28 after surface and end treatments.

Diode Bonding

Diode bonding fixture

- Six identical stations.
    - Crystal held vertically.
    - Nylon pins maintain crystal alignment.
    - Nylon block at base of fixture holds PIN diode in place.
    - Pre-measured amount of Epotek delivered to PIN.
    - Weight of crystal provides standard pressure on diode bond.

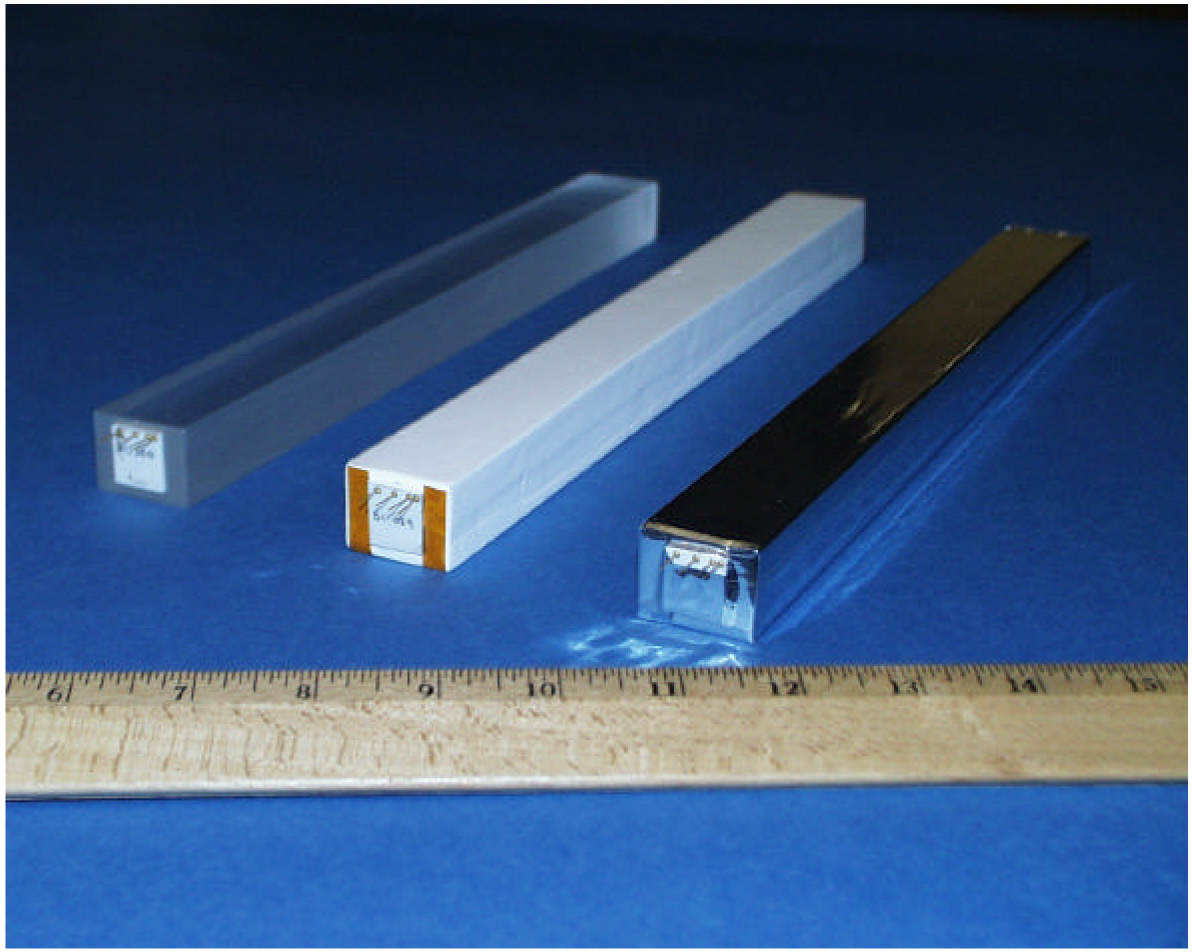


Crystal Wrapping

Processing of CsI crystals.

After acceptance testing in temporary wrap. After PIN diodes are glued on the ends.

Final wraps of Tetratek and aluminized Mylar are applied.

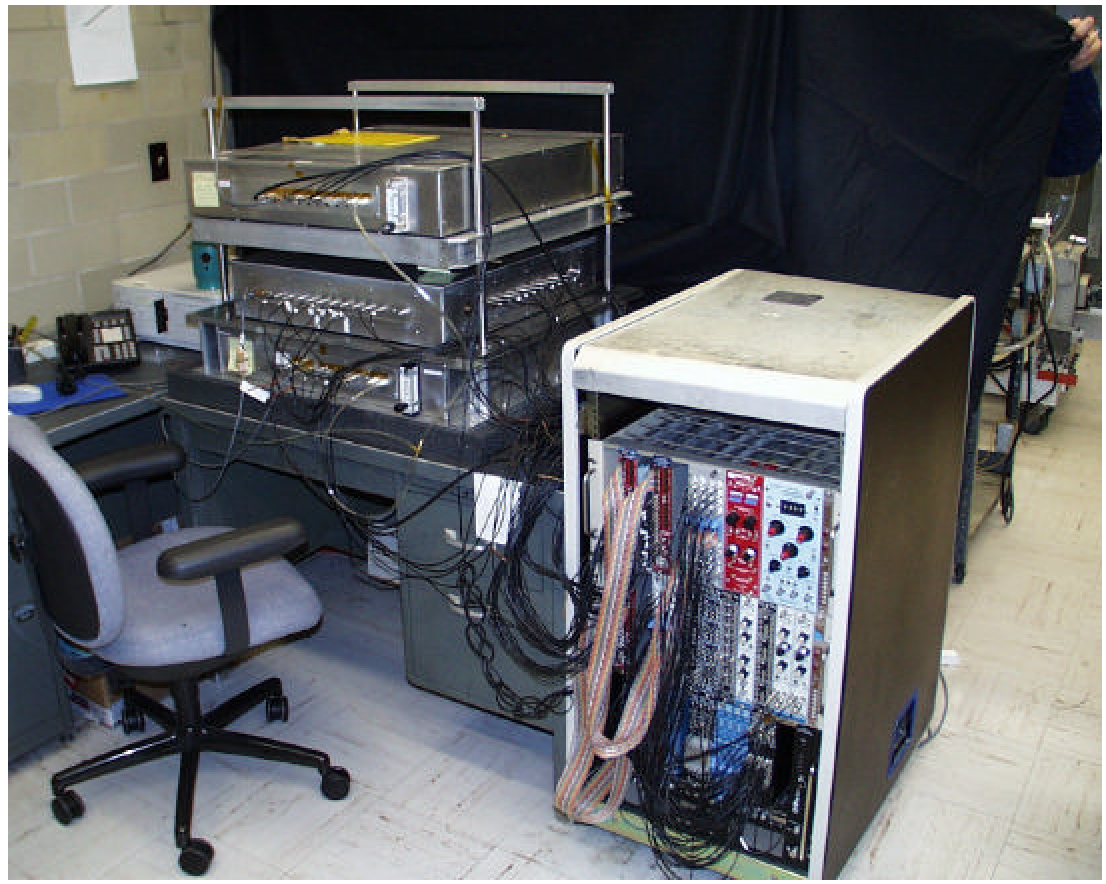


Muon Telescope

- Muon telescope.
- Stack 20 crystals at once.
  - 10 in x and 10 in y.
  - eV5093 preamps.
  - Crystal geometry naturally defines 10 longitudinal bins for each crystal.
- 2-dimensional wire chambers above and below provide trigger and finer muon tracking.

Muon Telescope

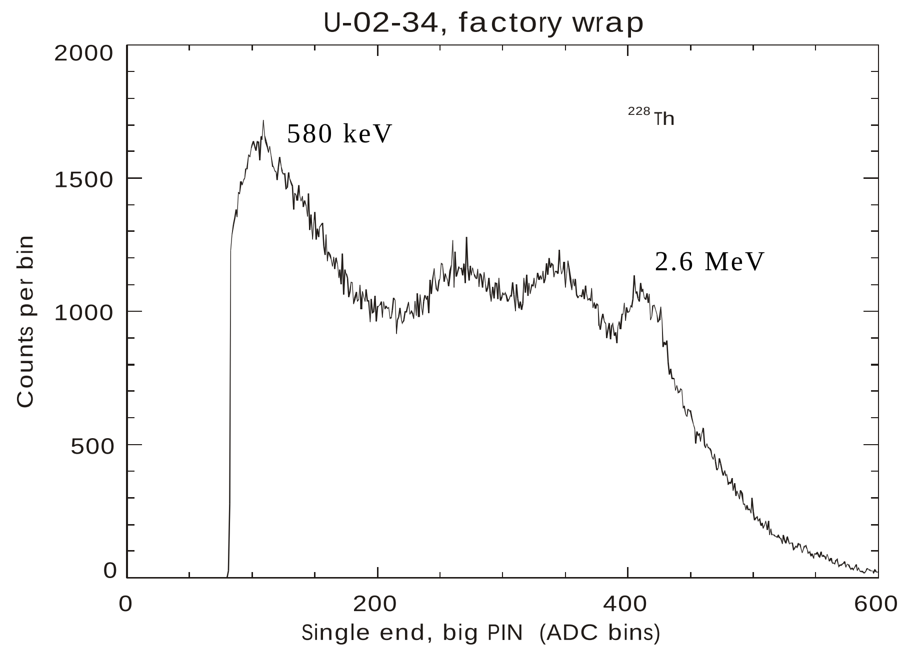
- Telescope assembly.
  - 2D wire chamber.
  - Crystal housing.
  - 2D wire chamber.
- CAMAC data acquisition system.
- IDL analysis s/w fits muon peaks and generates map hardcopy.
- Telescope can be expanded to accommodate full calorimeter tower.



Final Performance

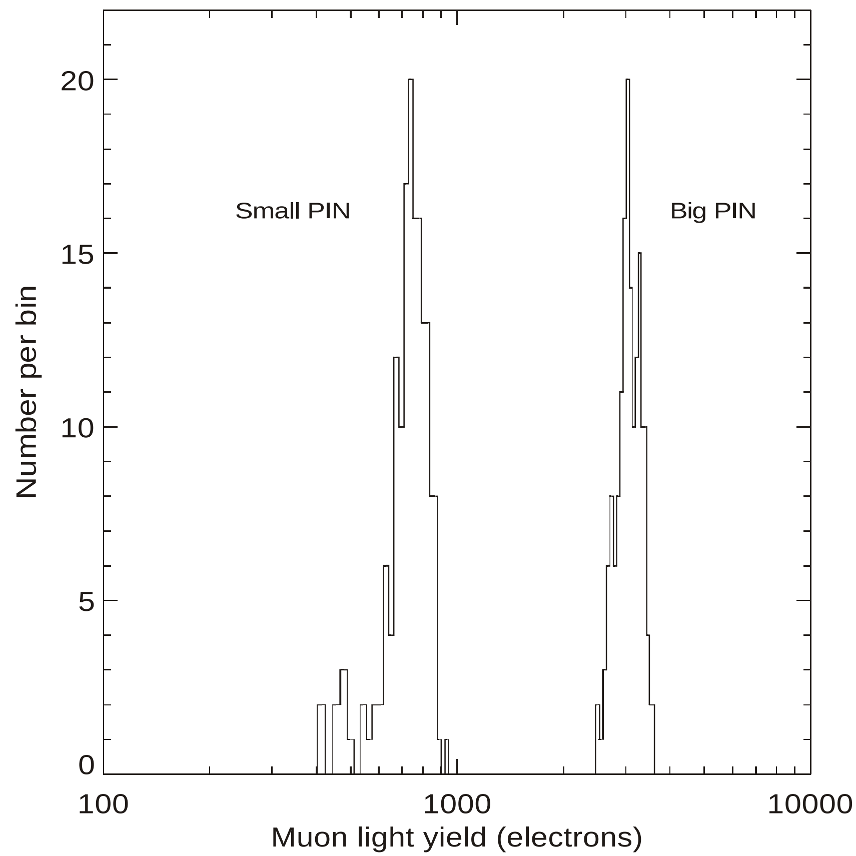
- Crystals with final surface and end treatments achieve excellent performance with custom dual PIN.

- Ukrainian crystal.
- Spectrum of ^{228}Th in 1 cm^2 custom dual-PIN.
- Factory wrap.
  - Tyvek with aluminum foil.
  - Tetratek gives ~20% more light.
- Laboratory bench electronics.



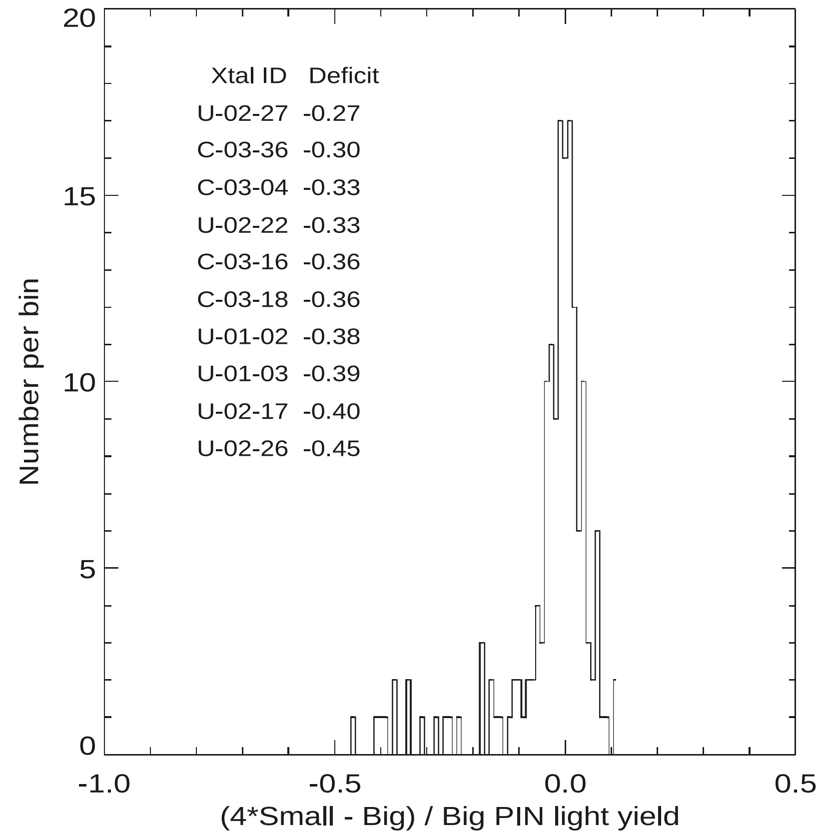
Distribution of Light Yields

- Light yield of Crismatec and Amcrys bars, with final surface treatment and final wrap.
  - Variation from bar to bar is small.
    - rms light yield in big PIN = 4%.
    - Crismatec and Amcrys bars are *indistinguishable*, despite the obvious difference in optical opacity: Crismatec bars are clear, while Amcrys bars are milky!
  - Mean yield
    - in 1-cm^2 PIN = 3000 e/MeV.
    - in ¼-cm^2 PIN = 750 e/MeV.
  - Note crystals with low yields in small PIN…



Distribution of Light Yields

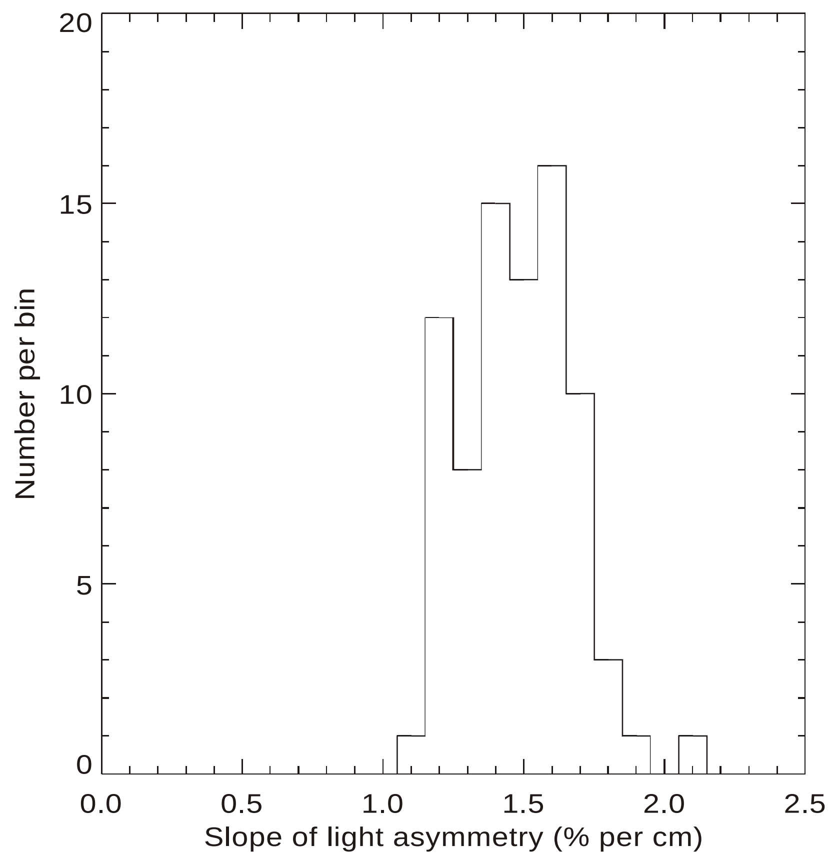
- Some optical bonds to small PIN were poor.
  - Poor bonds not detected in bench checkout because ^{228}Th photopeak is not detectable in small PIN.
  - Next time: check all bonds with muons immediately.
  - Fractional difference in yield in small PIN relative to corresponding big PIN:
    - f = $(4Y_S - Y_B) / Y_B$
    - Factor of 4 accounts for difference in geometric area.
    - Rejected crystals based on this ratio, or placed them in top of BTEM calorimeter, where small PIN is less useful.



Distribution of Slopes (Light Attenuation Lengths)

- Fit linear model to light yield as a function of position for each end of crystal.

- Crismatec and Amcrys bars with final surface treatment and wrap.
    - Mean slope = 1.5% per cm
    - rms of slope = 0.3% per cm
      (20% of mean slope)
    - Mean slope corresponds to end-to-end attenuation of ~0.4, i.e. response at far end is 40% of response at near end.



CsI Testing and Trade Studies

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Radiation damage

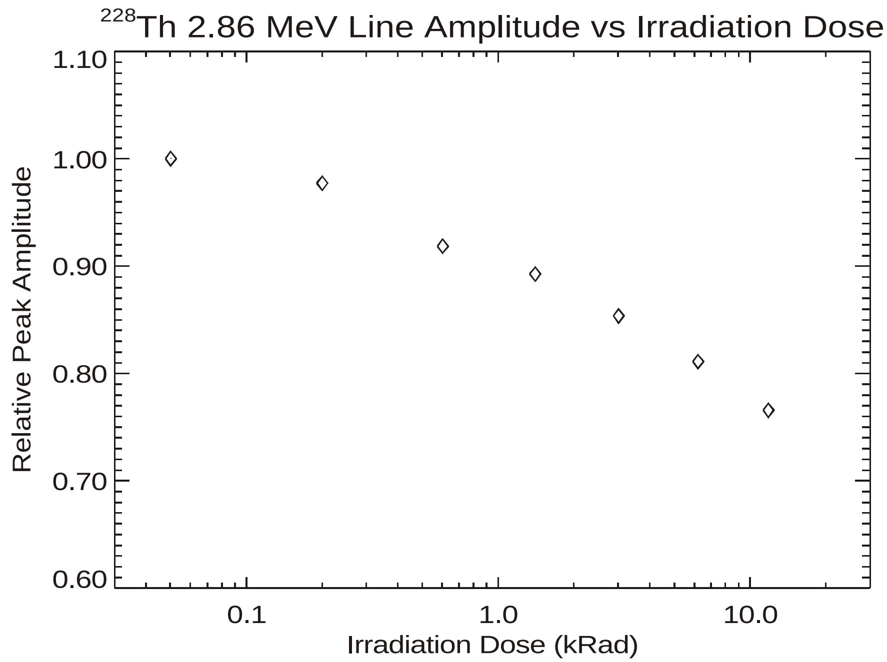
Detector packaging: wraps or paints

Pressure testing on wraps

End treatments: white or black

Radiation Damage

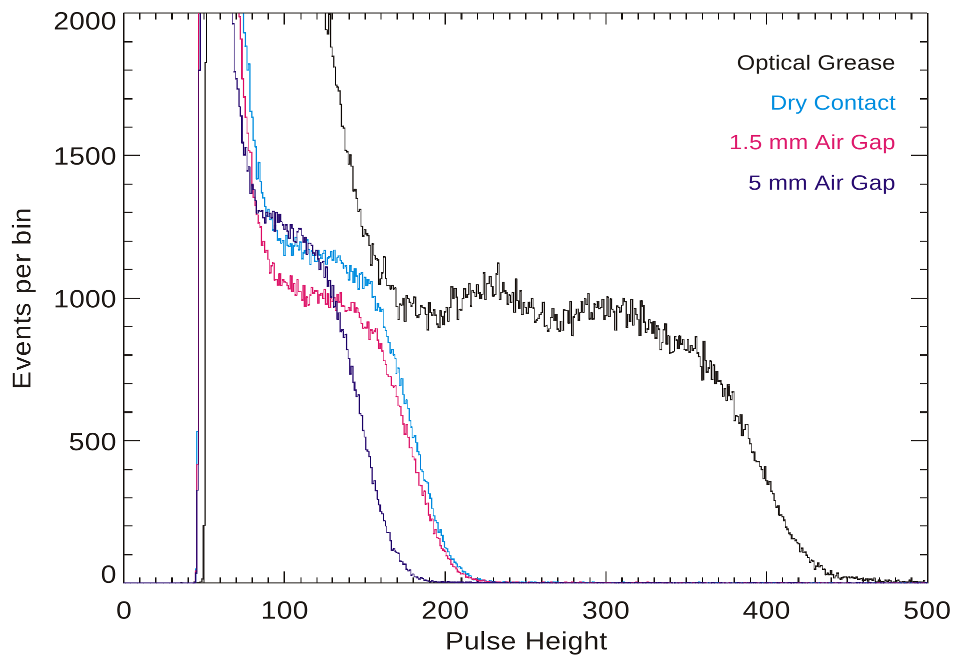
- NRL's ^{60}Co Irradiation Facility
  - Dose rate ~50-200 Rad per hour.
  - Horiba 240 x 30 x 25 mm crystal.
  - S3590 PIN readout on both ends.
  - Results consistent with Woody et al. (BNL reprint).
  - Degradation caused by decrease in effect light attenuation length.
- Estimated on-orbit dose <1 kRad per year.
- ~20% degradation in light yield for full mission.



Effect of Air Gaps

- Should diodes be strongly coupled with crystal face, or is an air gap adequate?

- Crismatec 370 x 30 x 23 mm crystal.
  - Final Tetratek + Al-Mylar wrap.
  - eV5093 preamps and lab electronics.
  - Far end: dual PIN with optical grease.
- Near end: dual PIN on fixture that allows varying separation between crystal face and diode face.
  - **5 mm**, 3 mm, and **1.5 mm gaps**.
  - **Dry contact.**
  - Optical grease.



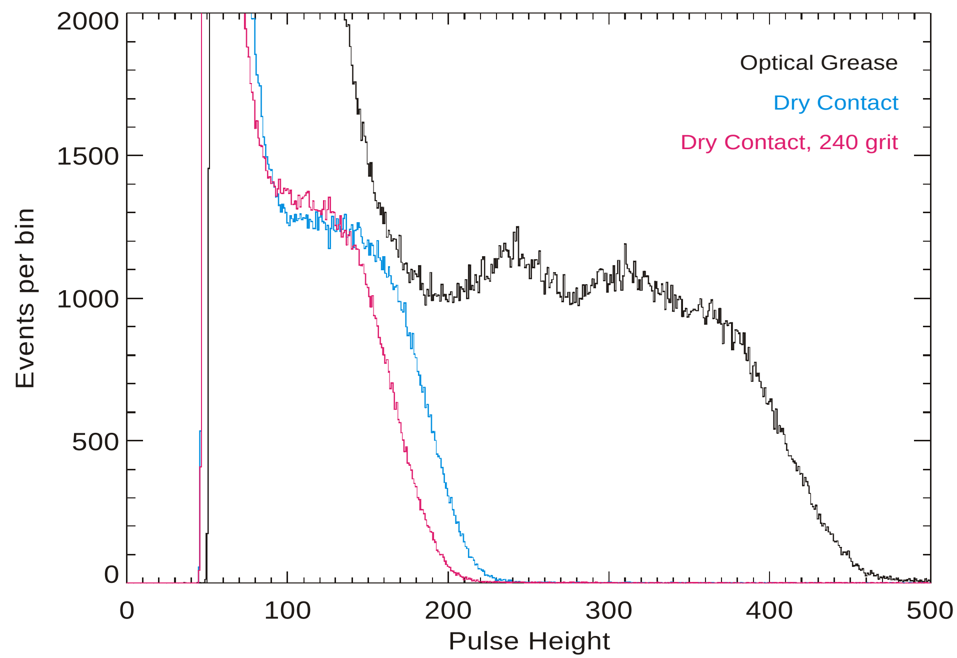
- Gap reduces light by factor of two or more.
- Must compare against optical grease rather than dry contact!

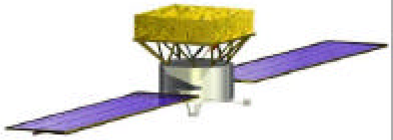
Effect of Air Gaps

- Does polishing or roughening the end face make any difference?

- Crismatec had finely polished end.
- Amcrys crystal with polished end.
  1. **Polished end, dry contact.**
  2. Roughened with 400-grit sandpaper, dry contact. Not shown.
  3. **Roughened with 240-grit sandpaper, dry contact.**
  4. Optical grease.

- Roughening the surface does not improve light yield.



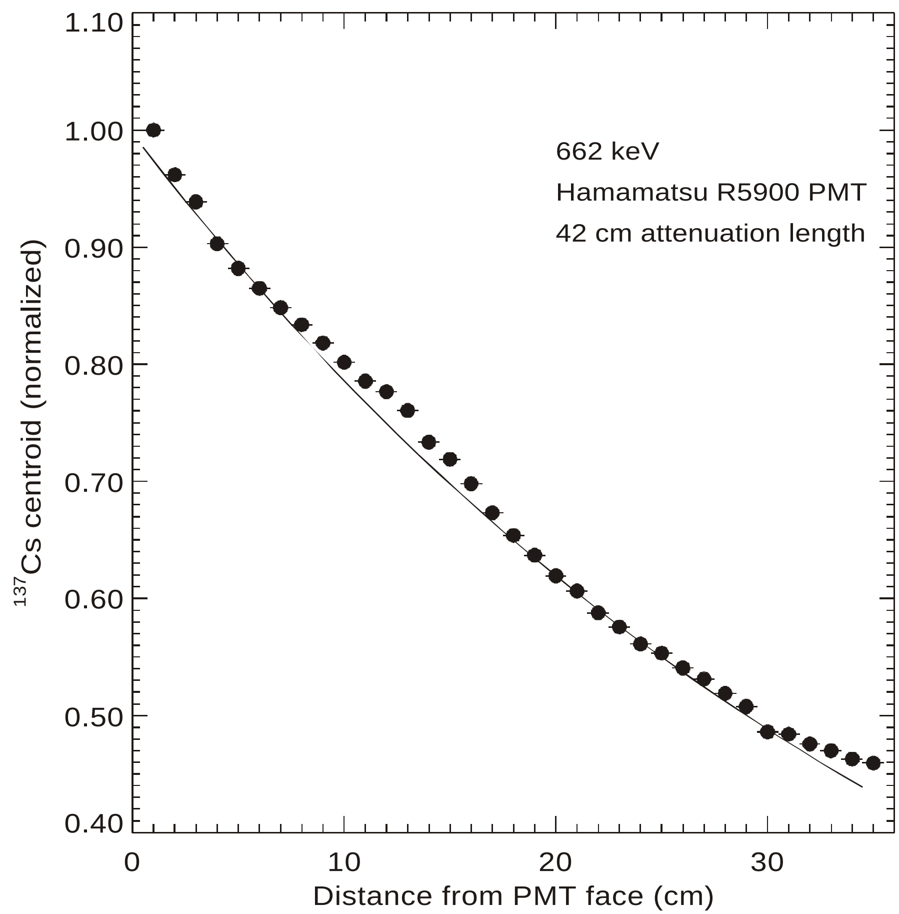


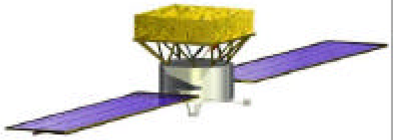
Position Response of CsI

Map of scintillation in 36 cm CsI crystal.

- ❑ Scanned ^{137}Cs source (662 keV).
- ❑ Crystal viewed full-face by PMT (connected with optical grease). Far face was blackened.
- ❑ Side wrap was Tetratek and aluminized mylar.

- ❑ Scintillation light yield drops by ~ half over length of crystal.
- ❑ Solid line is 42-cm exponential attenuation length.
- ❑ "Hotspot" at ~ 13 cm is real. ~2-3% magnitude similar to BaBar hotspots.



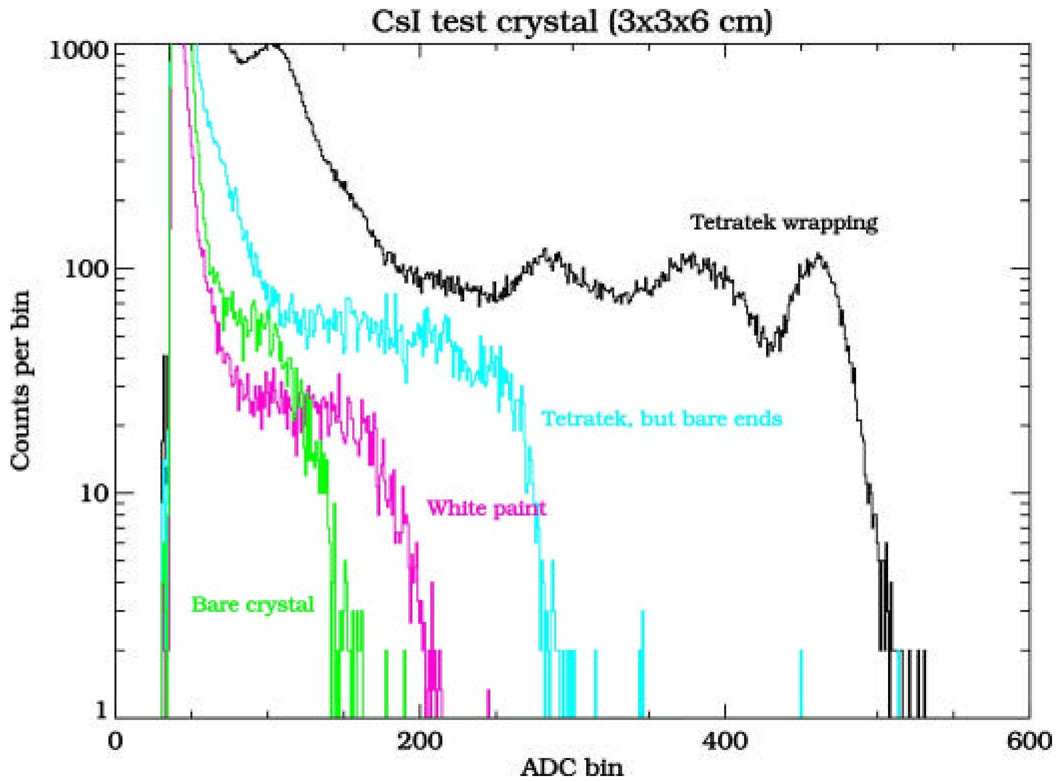


Detector Packaging / Light Collection Properties

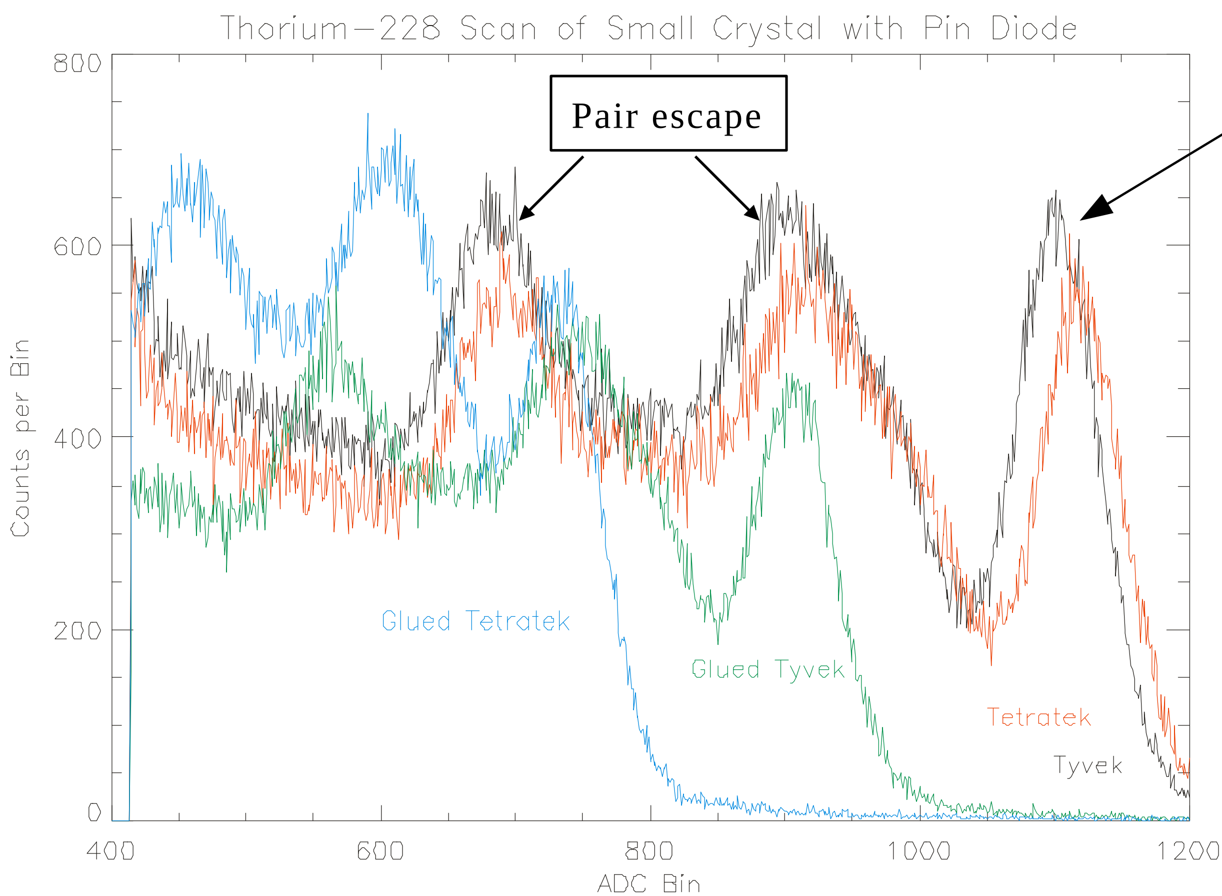
- Study of light collection impact of various crystal wrapping techniques:
  - treatment of CsI block ends vs light output
  - Tyvek, Tetratek, and paints
  - Tyvek & Tetratek laminated with Aluminized mylar
  - laminates attached to crystals with adhesives
  - * Paints are out, laminates show promise
- Study of compressive load impact on light collection for various wrapping techiques
  - * Short-term loss not significant, longer tests in progress

Paints/wraps

- Tests conducted on 3x3x6 cm bar with 1 cm^2 PIN diode.
    - Painting sides reduces light by more than factor of two.
        - Color of paint is irrelevant.
        - Conformal coating before painting is same as painting directly (not shown here).
    - Bare crystal in large Al box gives still less light.
- Wetting crystal surface is not a good idea: light is piped out.



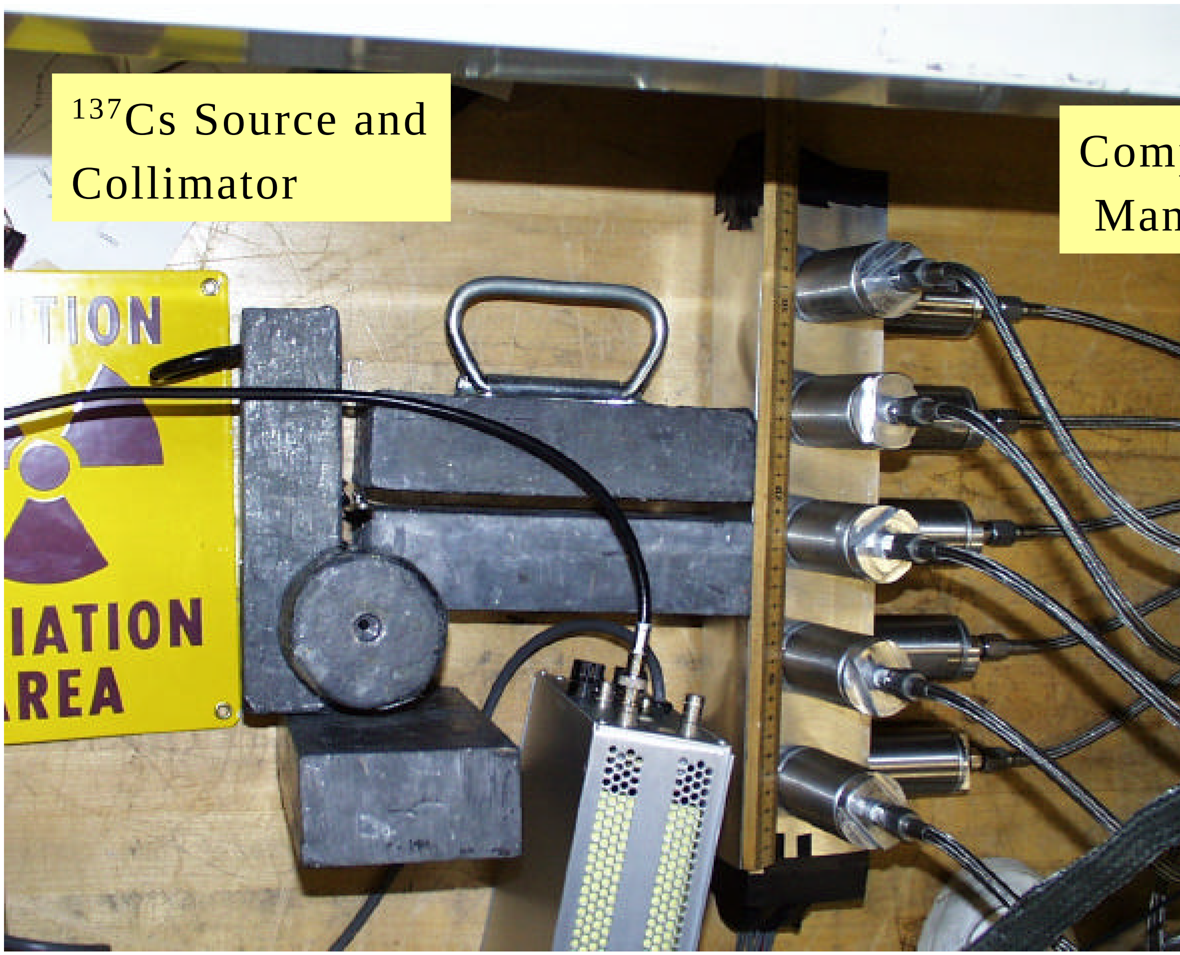
CsI Light Collection vs. Wrapping Techniques



- 6-cm CsI Detector
- ^{228}Th source
- Two wrappings with and without adhesives

- Again, wetting the crystal surface is not a good idea.

Detector Light Collection Test Unit



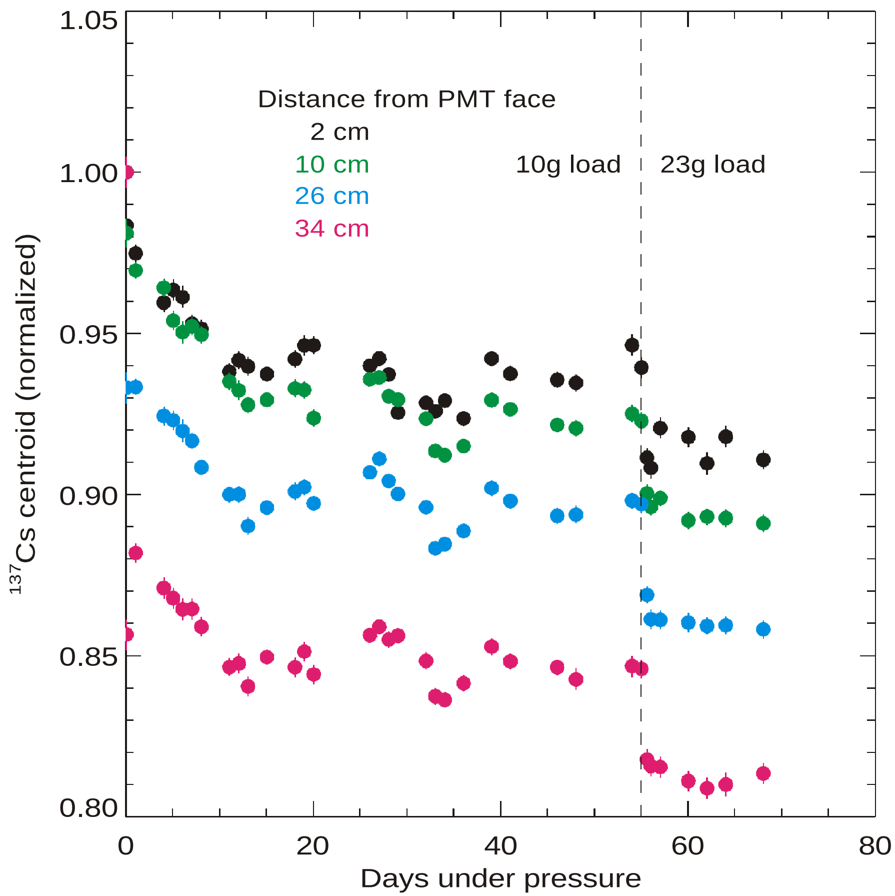
- 36 cm detector viewed by PMT
- Crystal scanned by ^{137}Cs source in Pb collimator
- Compression controlled by regulator and high pressure Nitrogen

Long-term Pressure Tests

36-cm crystal, Tetratek and mylar wrap, held under pressure and scanned.

- >50 days of 10-g load on all surfaces.
  - All curves normalized to first measurement.
- Light yield decreases under pressure.
- Light yield stabilizes after ~10 days at ~5 - 15% loss.

- Pressure increased to 23 g.
- Light yield rapidly stabilizes at an additional ~3% loss.



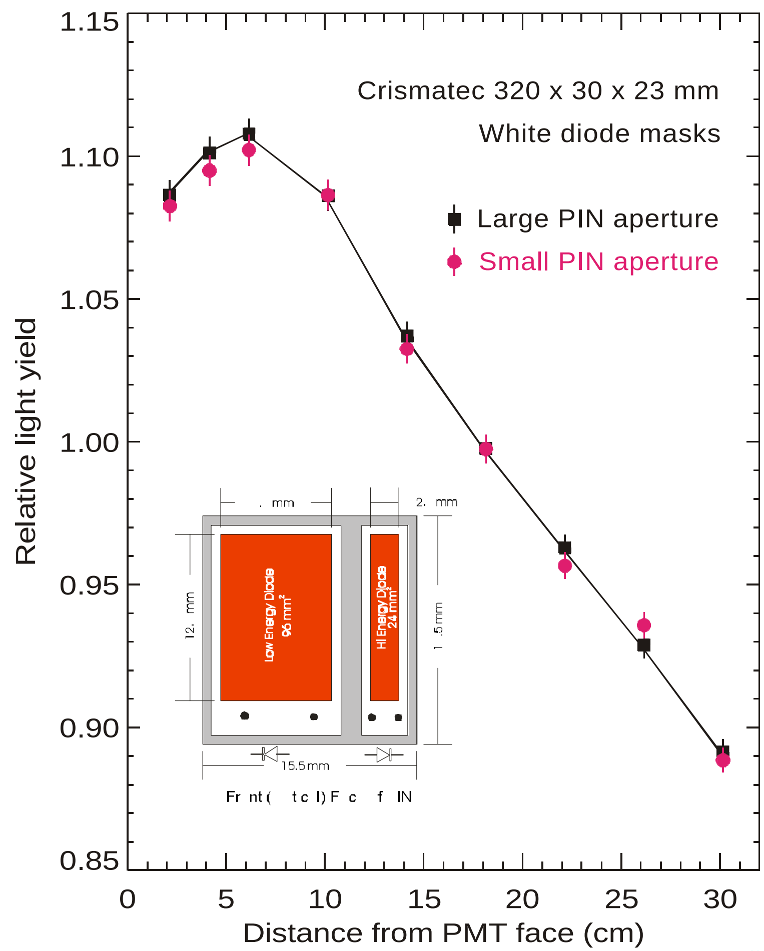
32-cm crystal scanned with ^{22}Na.

- ❑ All surfaces polished. Tetratek wrap.
- ❑ Viewed by PMT with air gap.

- ❑ Near face masked with Tyvek.
- ❑ Two masks, different apertures:
  - Size and location of large PIN.
  - Size and location of small PIN.

- ❑ Light tapering is independent of aperture size.
- ❑ Attenuation length (beyond 10 cm)

  λ = 110 cm.



End Treatments: Black Mask

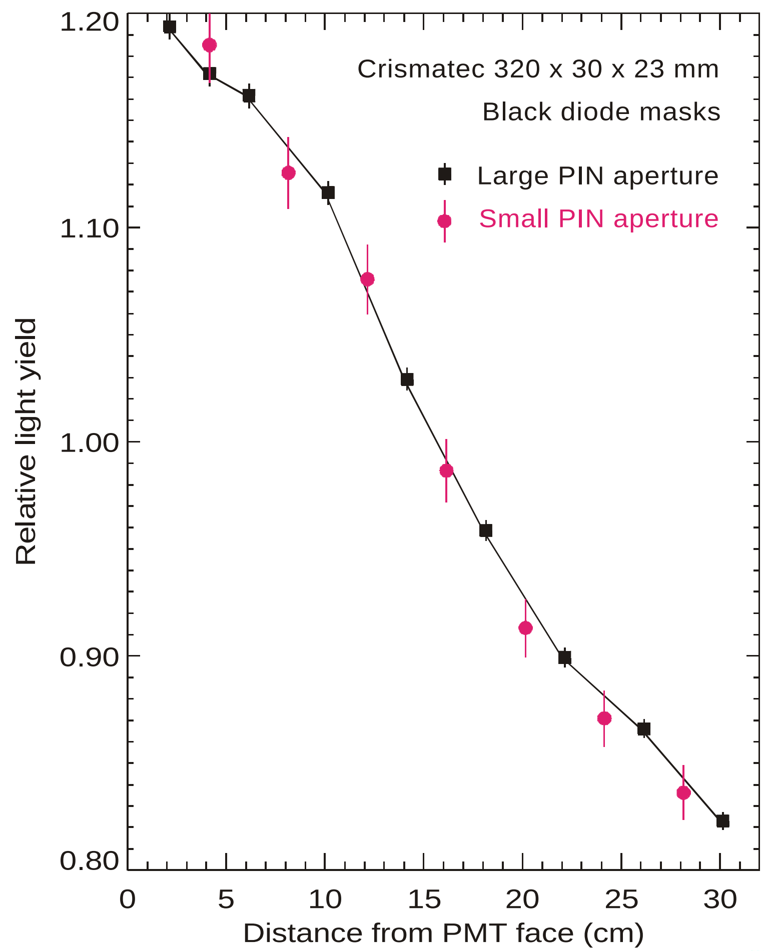
32-cm crystal scanned with ^{22}Na.

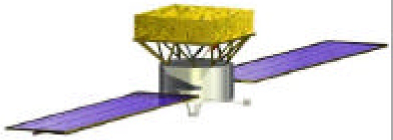
- ❑ All surfaces polished. Tetratek wrap.
- ❑ Viewed by PMT with air gap.

- ❑ Near face masked with black paper.
- ❑ Two masks, different apertures:
  - Size and location of large PIN.
  - Size and location of small PIN.

- ❑ Light tapering is independent of aperture size.
- ❑ Attenuation length (all crystal)

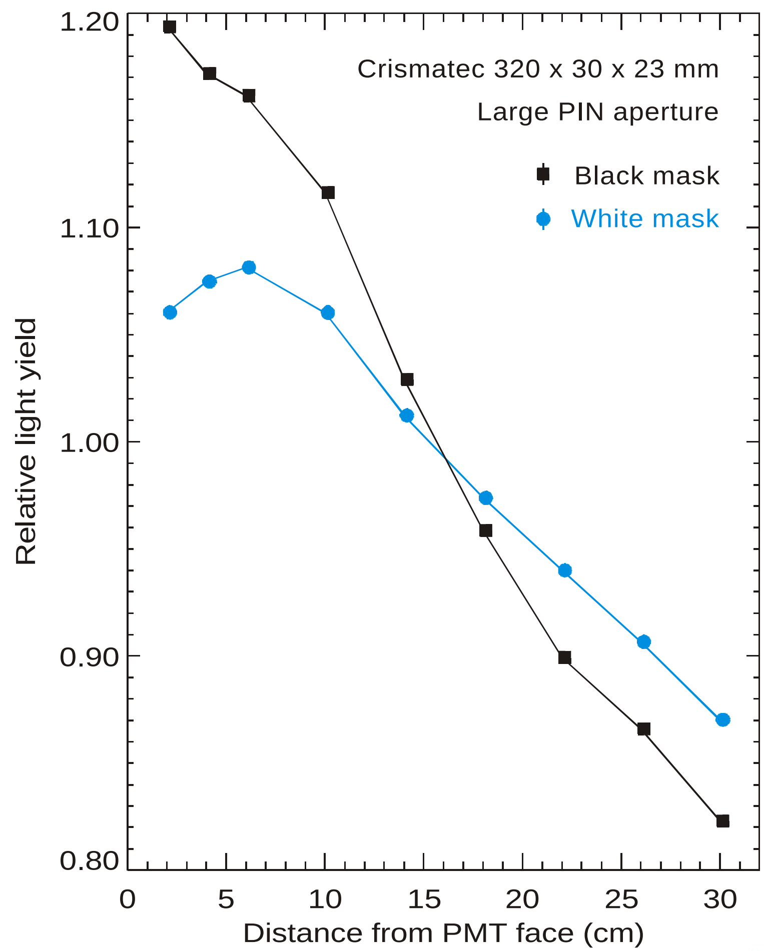
  λ = 75 cm.





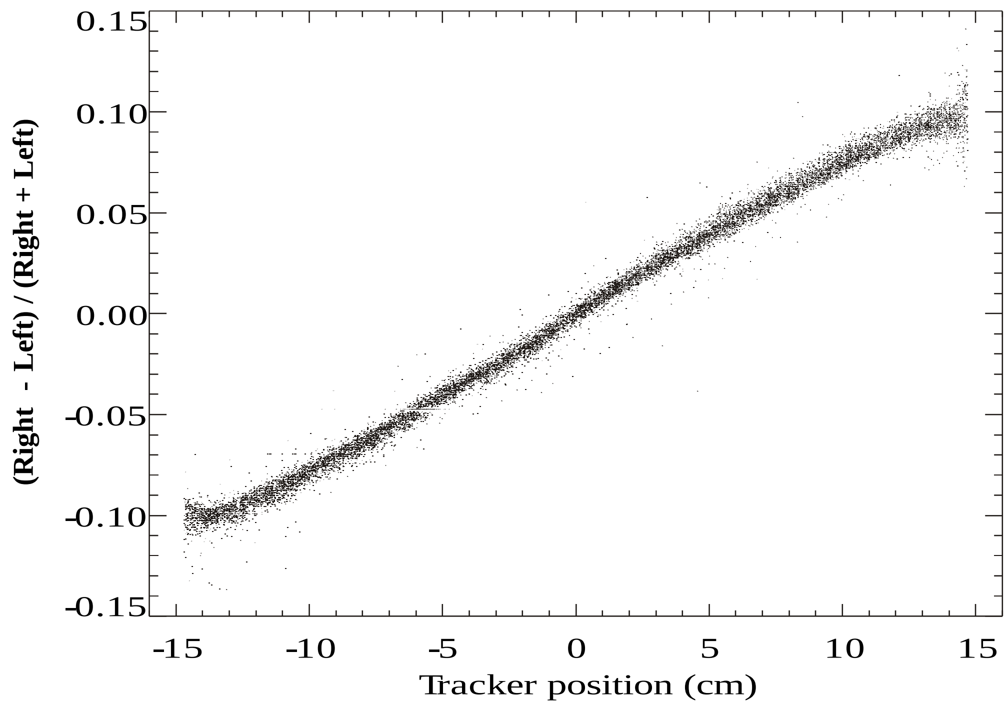
Black or White Ends?

- How does end treatment affect light yield and attenuation?
  - 32-cm Crismatec crystal mapped with ^{22}Na source.
  - PMT readout with black or white aperture mask (~1 cm^2 open).
- Black mask reduces light S to ~2/3 of white mask.
- Black mask shortens attenuation length.
  - λ = 75 cm for black
  - λ = 110 cm for white
- Position resolution scales as $\lambda / \sqrt{S}$
  - Black mask gives
    - 1/3 less light, but
    - 20% better position resolution.



32 cm CsI Bar Position Resolution

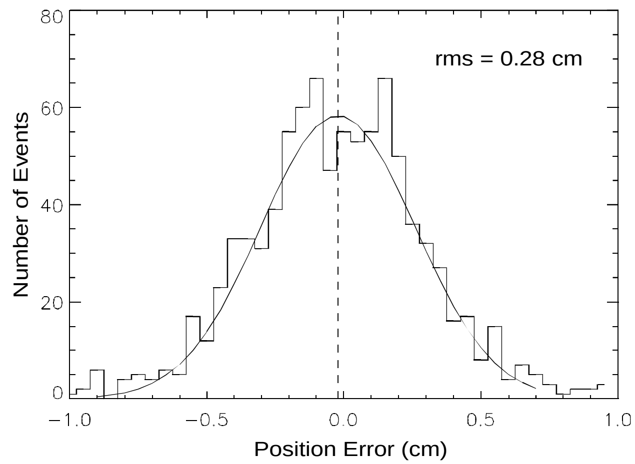
Light Asymmetry



Position Resolution

SLAC e$^-$ beam, 2 GeV

ΔE ~ 130 MeV



Various Beam Test Results

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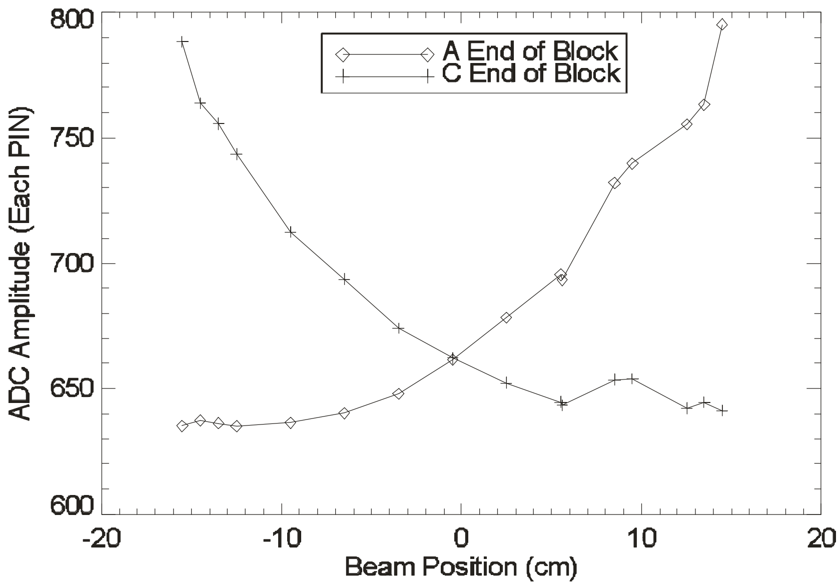
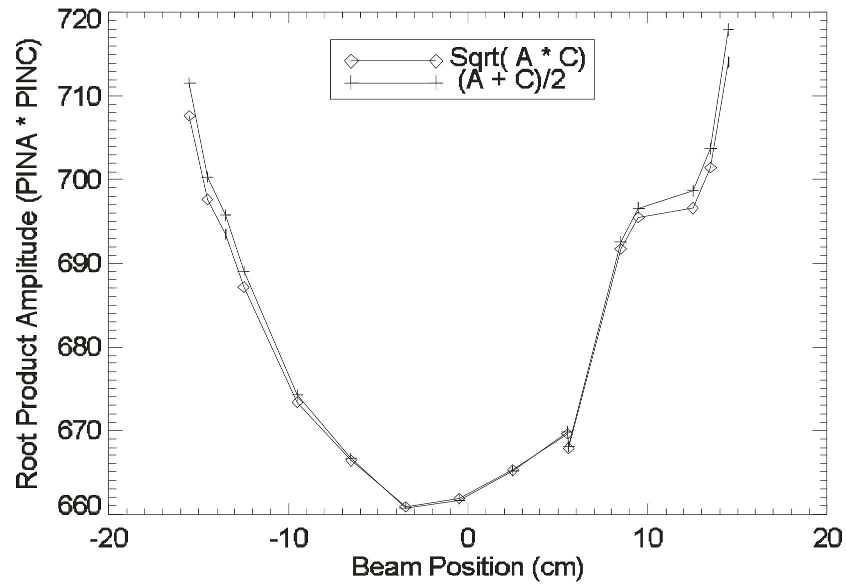
MSU Beam Test '98 - He Beam

Each End of CsI Block



Sum of Ends of CsI Block



Light amplitude seen at each end of the 32 cm CsI block as a function of position.

Sum of signals from both ends of the 32 cm CsI block as a function of position.

He Beam: 160 MeV/nuc
Energy Deposition: ~150 MeV

Variation with position: ± 4%

Position Resolution, SLAC '97

Longitudinal position resolution:

- σ_x = 0.04 cm – 0.4 cm.
- 3 x 3 x 19 cm crystals.

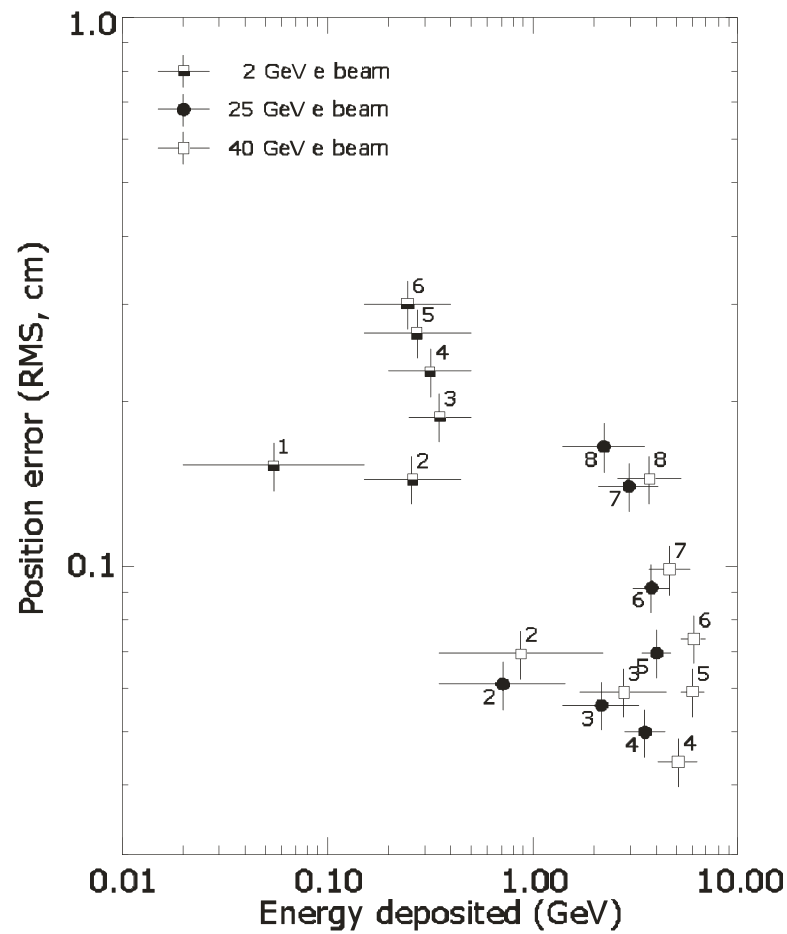
Position resolution is a function of:

- Slope of asymmetry measure;
- Energy deposited in crystal;
- Shower multiplicity;
- Transverse development of shower.

Light attenuation length:

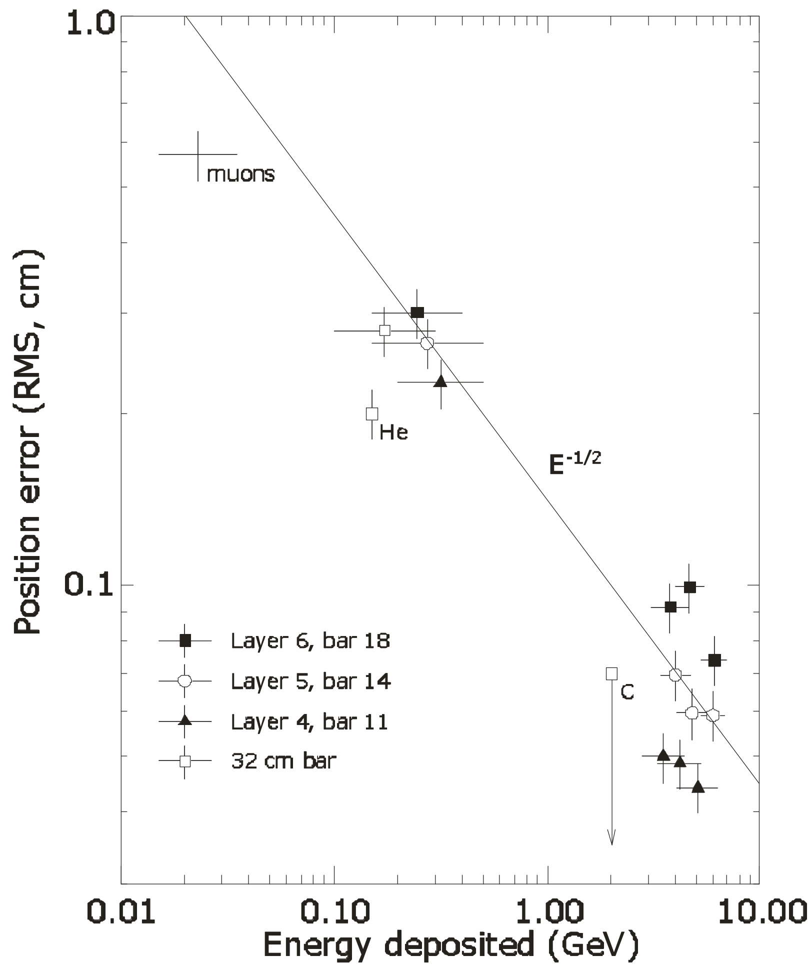
$x = \lambda \times (R-L) / (R+L)$

λ = 40 cm – 120 cm.



SLAC Beam Test 97

For a given CsI bar, position resolution does indeed scale roughly as $1/\sqrt{E}$.



CERN Beam Test '98